Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

THE RELATION OF SOILS TO NATURAL VEGETATION IN ROSCOMMON AND CRAWFORD COUNTIES, MICHIGAN.[1]

CONTRIBUTIONS FROM THE HULL BOTANICAL LABORATORY. LXVI.

BURTON EDWARD LIVINGSTON.

(WITH MAP)

IN a study[2] of the distribution of vegetation in Kent county, Michigan, made by the author several years ago, the tentative conclusion was reached that the controlling factor in the distribution of the plant societies on the upland is the amount of water in the soil, and that this in turn is determined by two conditions, the nearness of the underground water level to the surface and the water-retaining or capillary power of the surface layers. This last factor is dependent largely upon the size of the soil particles. It was thought well to continue this subject farther north, using the same methods. Accordingly in the summer of 1902 the work here reported was accomplished. It covers nearly all of Roscommon county and the southern half of Crawford county.

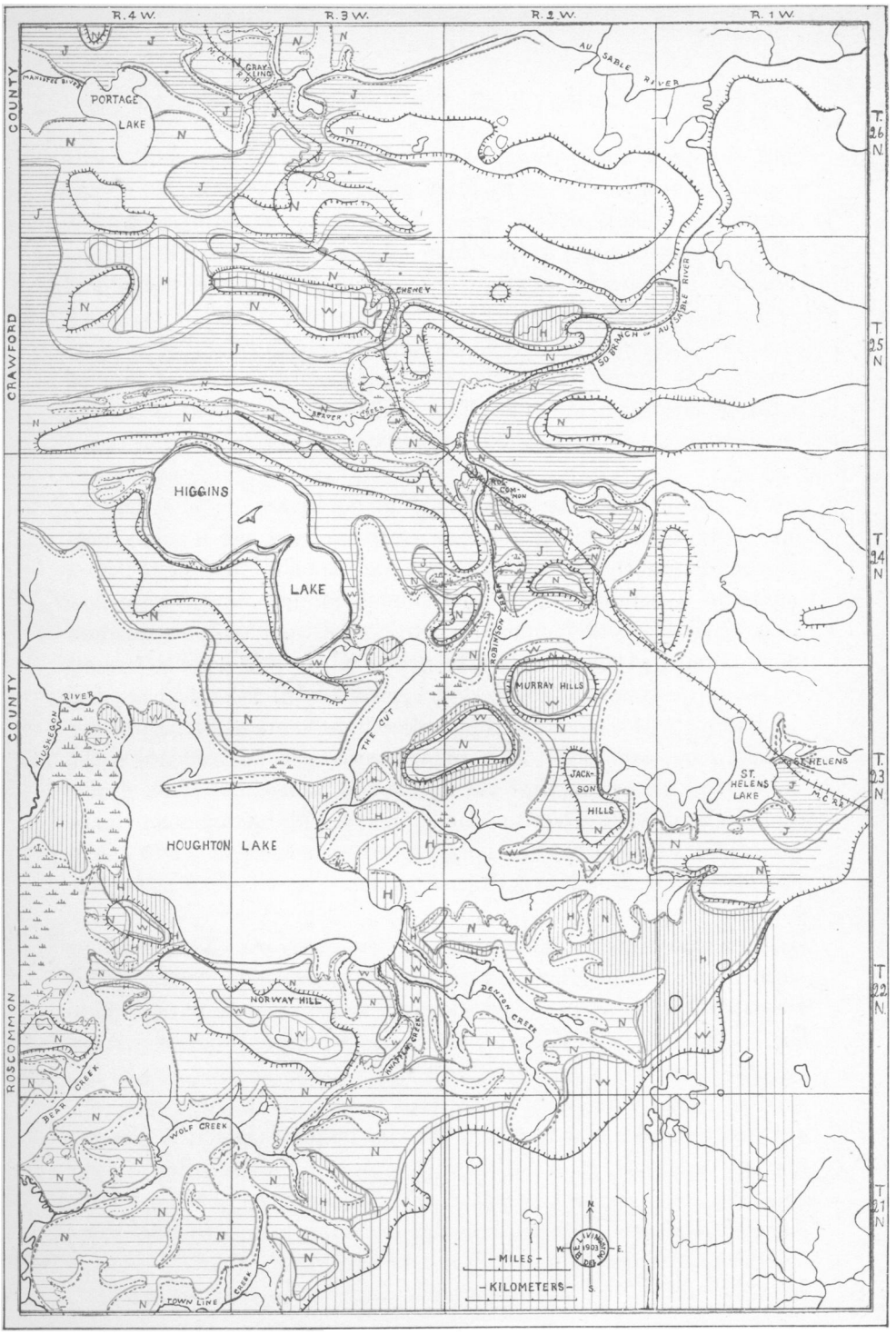
TOPOGRAPHY AND SOILS.

The region consists of a series of ridges and depressions. The former are sometimes several miles wide but more often narrow; they are always comparatively low, seldom rising more than 50 to 60 m above the level of Higgins Lake, which lies in the middle of the

[1] Published by permission of the U. S. Bureau of Forestry and of the Michigan Board of Geological Survey. A more detailed account of the investigations here recorded will appear in the Annual Report of the Michigan State Geologist, 1903. The map here presented is from the last-named report. A very brief statement of the conditions in this region has been published in the Report of the Michigan Forestry Commission, 1902.

[2] LIVINGSTON, B. E., The distribution of the plant societies of Kent county, Michigan, Ann. Report Mich. State Board Geol. Survey **1901**: 81–103.

——, The distribution of the upland plant societies of Kent county, Michigan. Bot. Gaz. **35**:36–54. 1903.



Livingston on Soils and Vegetation.

Moraine margin	———	Clay	
Swamp and channel margin	- - - -	Clay loam	
Soil margin		Loamy sand	
Vegetation margin	———	Sand	
Hardwood	H	Norway pine	N
White pine	W	Jack pine	J

area. These ridges are moraines and between them are lower and more level stretches consisting for the most part of plains which slope downward from the ridge margin to the nearest stream. The surface soil of these plains is almost pure sand in many instances, while in others it contains enough more finely divided material to be termed loamy sand. Gravel deposits are very rare and it is seldom that one finds in the plains even scattering pebbles. The moraines are more heterogeneous in composition, containing clay, loam, and gravel as well as sand. An accurate description of these features is to be found in the geological report referred to, and will be here omitted. (See map.)

The soils are nearly all sandy, the only exception to this statement being a few low clay areas and certain clayey portions of the larger moraines. The surface soil of most of the ridges is gravelly and loamy sand, the predominating sand containing a sufficient admixture of finer particles to produce a marked difference in physical properties from that of the true sand plains, while they also contain pebbles and sometimes scattered bowlders. The slopes downward from these ridges are of sand, either pure or loamy, seldom containing many pebbles of any considerable size. The true sand plains, which lie at the bottom of some of the valleys, contain little or no loamy material and no pebbles. Their surface is a fine grayish-white sand, which drifts readily by the wind when loosened. Obviously difference in degree of water-washing determines these different soil characters.

Sandy soils are composed of coarse particles and contain much silica, loamy soils are of finer particles and contain considerable quantities of alumina, while clay soils are of still more finely divided materials and contain a much larger percentage of alumina. Since all of this material was transported from the north by the glacial ice, and since it must have been quite thoroughly mixed by this agency, it is reasonable to suppose that, had it not been washed by water during and after its deposit, it would be at least fairly uniform in its mineral constituents. The washing process sorted the soils according to size of particles, but also according to their chemical nature. This is partly due to the fact that alumina breaks down into fine particles more readily than does silica. It is also due to the

fact that in well-washed soils even the less soluble constituents are apt to be actually dissolved and washed out to a greater or less degree. Thus, phosphates and sulfates are less abundant in well-washed soils than in those less thoroughly washed.

In this glaciated region, fine soils, such as clay, were either deposited under the ice of the glacial epoch, and hence not well washed, or else they were deposited from deep and very slowly flowing water. The former variety usually contains many coarser particles, as loam, sand, and pebbles. In the case of loamy soils a good part of the fine material has been washed out, but a considerable amount remains with the sand, so as to give it its loamy character; this is especially true of the ridges. Sandy soils are still more thoroughly washed; the gravel was left farther up stream, on the sides of the ridges usually, while the clay was held in suspension to be deposited at a lower level, where the velocity decreased.

On account of the difference in size of particles, which results from water washing, there naturally follows a corresponding difference in the size of the interstitial spaces of the soil; the finer the component particles, the smaller must be the spaces between them. And because of this there comes to be a corresponding difference in water-holding power and water-lifting power. The surface tension of water films is greater and hence more effective over small curfaces than over large ones, and the film surfaces are greater in coarse than in fine soil. Thus, the smaller the particles of any soil the more water it can hold and the higher it can lift this liquid from a lower level. WARMING[3] quotes WOLLNY as having shown that quartz sand consisting of grains over 1 to 2^{mm} in diameter can hold only one-tenth as much water as that with grains 0.01 to 0.07^{mm} in diameter. SCHIMPER[4] states that loose sand has a water capacity of 15.7 per cent. of its volume, while clay exhibits this property to the extent of 40.9 per cent.

The nature of the soil particles themselves often plays an important part in determining the water-retaining and water-lifting power.

[3] WARMING, E., Lehrbuch der ökologischen Pflanzengeographie, übersetzt von Dr. E. Knoblauch. Bearbeitet von P. Graebner. Berlin. 1902. p. 55.

[4] SCHIMPER, A. F. W., Pflanzengeographie auf physiologischer Grundlage. Jena. 1898. p. 94.

Especially is this true in the case of humus, which is composed of organic débris, decayed plant parts, and to some extent of animal offal. Pure humus has a great power to hold and lift water. This is partly because of its very fine particles, but is also to be traced in part to the actual penetration (by imbibition) of the liquid into the intermolecular spaces of the organic substance itself. Thus, by admixture of humus to a coarse (and therefore porous and permeable) soil, the water capacity of such a soil is increased. The filtering power or permeability to water of a soil increases of course with decrease in its capillary power. Also its permeability to air increases in the same way.

A general exposition of this question of size of particles, water-retaining power, etc., is to be found in either of the works just cited. A much better treatment, however, has appeared in the publications of BRIGGS[5] and WHITNEY.[6] The reader is referred especially to the writings of the former author.

Chemical analyses of a number of Michigan soils have been made and published by KEDZIE.[7] Table I, showing chemical constituents and water capacity, is compiled from his pages, the samples described being all from the portion of the state in which the present studies were made. The first column gives the chemicals found in the soil, in per cent. of dry weight, excepting in the case of water capacity, which is presumably given in per cent. of total volume—although this is not stated in the original papers. The upper tier gives the kind of soil, the location, and the nature of the forest cover.

[5] BRIGGS, L. J., The mechanics of soil moisture. U. S. Dept. Agric., Div. Soils, Bull. 10. 1897.

——, Investigations on the physical properties of soils. U. S. Dept. Agric., Field operations Div. Soils, 1900–1901. pp. 418–421.

[6] WHITNEY, M., The Division of Soils. Yearbook U. S. Dept. Agric. 1897. pp. 120–125.

——, Soil moisture. U. S. Dept. Agric., Div. Soils, Bull. 9. 1897.

Also see WHITNEY, M., and CAMERON, F. K., The chemistry of the soil as related to crop-production. U. S. Dept. Agric. Bull. 22. 1903.

[7] KEDZIE, R. C., The jack pine plains. Mich. Agric. Exp. Sta., Bull. 37. Also, 27th Ann. Rept. Secy. State Bd. Agric. 1888. pp. 207–210.

——, The soils of Michigan. Bull. 99. Also, 52d Ann. Rept. Secy. State Bd. Agric. 1894. pp. 403–415.

TABLE I.

SHOWING RESULTS OF ANALYSES OF SOILS OF NORTHERN MICHIGAN.

	Location	Tittabawassee Valley	Mecosta co.	Gaylord	Missaukee co.	Lake co.	Average, 6 samples, Crawford and Oscoda cos.
Physical Description	Nature of soil	Clay	Loam	Loam	Loam	Sand	Sand
	Water capacity	51.40	45.40	39.60	39.10	35.30	33.00
	Forest type	Hardwood	White pine	Hardwood	Hardwood	Jack pine	Jack pine
Chemical Description	Silica	67.20	75.54	91.52	69.39	92.48	94.22
	Alumina	6.31	10.62	2.93	8.35	2.22	.....
	Fe	7.91	3.80	0.90	5.80	1.59	1.88
	Ca	1.64	0.94	0.40	1.15	0.35	0.37
	Mg	1.23	0.48	0.13	0.98	0.30	0.06
	K	1.85	1.96	0.61	1.95	0.73	0.85
	Na	1.15	1.25	0.28	1.15	0.32	0.27
	H_2SO_4	0.30	0.26	0.10	0.25	0.06	0.01
	H_3PO_4	0.49	0.44	0.14	0.28	0.14	0.08
	Organic materials	7.48	2.97	2.20	4.73	1.22	2.16

It will be noticed in the table that sandy soils usually exhibit a marked scarcity of soluble salts. This fact is perhaps to be explained by the "leaching" action of the percolating waters, as well as by the thorough washing to which these soils were subjected at the time of their deposition. The water of precipitation percolates rapidly through these porous soils and may often wash the soluble salts down toward the level of the ground water, this process being termed "leaching."

In humus-covered soils, it is probably not to the point to determine humus content and water capacity after the humus has been mixed with the loamy layers; the effect of the organic substance is very much more marked when the humus lies as a distinct layer on the surface than when it is distributed through the underlying soil. The humus layer acts like a sponge filled with water, and allows the water to pass slowly down into the underlying layers, and thus keeps them moist much longer than they would otherwise be. The samples described above probably were taken from surface soil, perhaps reaching a depth of 20 to 30 ^{cm}; nothing is said regarding this question in the reports from which these data are derived.

Table II presents the water capacity of several soil samples col-

lected by the author in Roscommon and Crawford counties. The determinations were made in this laboratory. By "surface" is meant the first 5 to 6^{cm}, by "subsoil" the next 15 to 20^{cm}.

TABLE II.

SHOWING THE WATER CAPACITY OF ROSCOMMON AND CRAWFORD SOILS.

Sample No.	Township	Soil type	Topography type	Forest type	Water capacity volume per cent.	
					Subsoil	Surface
1	21.4	Clay loam	Plain	Hardwood	43.5	74.1 humus
2	22.4	Clay loam	Ridge	Norway	45.9	40.0
3	25.4	Sand	Plain	Jack	37.0	38.0
4	22.4	Loamy sand	Plain	Norway	43.5	....
5	22.4	Clay	Plain	Hardwood	56.9	Mainly humus

It is noticeable that the subsoil of *sample 1* has the same water capacity as that of *sample 4*, but the surface humus of the former brings its water-retaining power up to a point far above that of the latter. The surface of *sample 4* was apparently like the subsoil, containing very little humus.

TYPES OF VEGETATION.

The vegetation of the region may be subdivided into several types or plant societies. These grade more or less into one another, but there are a few places where an observer would be puzzled to determine any particular type. There are to be distinguished four types on the upland and three on the lowland. Practically all of the area under discussion has been lumbered. A virgin pine forest is almost entirely unknown now, though some of the finest pines of the state were cut from here. The hardwood areas have been left almost untouched, excepting for the removal of the white pine originally scattered through them in many places. The hardwood is now being rapidly removed, however, and it will not be long before there will be none left. In the lowlands, the merchantable arbor vitae has very largely been removed, as has been also much of the spruce and even considerable quantities of the tamarack. In the present description there will be presented first a characterization of the original vegetational cover, as well as this can be determined at the present time; then will follow a description of the present conditions.

1. *Upland types.*

A. HARDWOOD TYPE. There is very little hardwood in the region studied, but it is quite typical of all northern Michigan. Areas so covered have not been so thoroughly lumbered as those covered with pine forests. The original form of this type comprised the following characteristic trees:[8] *Acer saccharum*, *Fagus americana*, *Tsuga canadensis*, *Ulmus americana*, *U. racemosa*, *U. fulva*, *Abies balsamea*, *Betula lutea*, some *Picea canadensis* and *P. mariana*, often scattered *Pinus Strobus* of enormous size, together with such low forms as *Rubus strigosus*, *Mitchella repens*, *Lycopodium clavatum*, *Taxus minor*, *Amelanchier canadensis*, *Lappula virginiana*, *Hedeoma pulegioides*, *Solidago caesia*, etc. Acer, Fagus, and Tsuga make up three-fourths of the forest, now one and now another of the three being dominant.

Lumbering has affected this type very little, excepting by removing the white pine, and in some cases the hemlock. Hardwood lumbering is now going on in the areas covered by this type; in these operations everything is being removed which is merchantable. Fires have not injured this form of forest to any extent, and the original humus usually remains.

B. WHITE PINE TYPE. This is typical pinery, often containing little besides white pine. Usually, however, there is an intermixture of Norway pine (*P. resinosa*), and often of hardwoods. The type is quite sharply distinguished from the preceding, but not nearly so well marked off from the following type, into which it grades in many places. As has been stated, there is at present hardly any of this type in the region under discussion. In lumbering all the pine was removed, and the subsequent fires have killed the young growth of this tree as well as the scattering hardwoods. Over vast stretches originally covered with white pine there are now no trees at all. They are regions of dwarfed *Quercus alba*, *Q. rubra*, *Acer rubrum*, and a number of shrubs. The oaks and maples are rarely more than twice as high as a man, are burned down every few years, and exist here only because of the fact that they sprout from the roots, which are not always killed by the fire. These scrub oaks and maples

[8] The nomenclature is that of BRITTON and BROWN'S *Illustrated Flora*.

thus possess enormous roots which are partially dead or dying, gnarled, contorted, and deformed by frequent burning. For an interesting description of how maples, oaks, etc., are able to attain great age in this manner, and still not be over a few feet in height, the reader is referred to BEAL'S[9] paper on this subject, which is accompanied by convincing illustrations.

Among the lower forms occurring here may be mentioned the following: *Rhus hirta*, *Monarda fistulosa*, *Pteris aquilina*, *Gaylussacia resinosa*, *Vaccinium pennsylvanicum*, *V. canadense*, *Comptonia peregrina*, *Solidago hispida*, *Hamamelis virginiana*, etc. The ground between the blackened stumps is now thoroughly covered by densely growing sweet fern, huckleberry, and blueberry, the growth of the sweet fern being so luxuriant that the numerous prostrate logs are often entirely hidden from sight.

C. NORWAY PINE TYPE. At the time of lumbering, this type consisted mainly of the species for which it is named, but usually contained scattering white pine and more numerous though often dwarfed red and white oaks and red maples. The present aspect of this type is much the same as that of the preceding. The two oaks, red maple, and seedling Norway are the characteristic trees now. Seedling Norways are more numerous than in the preceding type, perhaps because of the greater number of seed trees here, as well as the somewhat greater ability of this species to withstand fire than that possessed by the white pine. The low plants are much the same as in the last. *Solidago caesia* of that type is replaced here by *S. juncea;* and *Lacinaria scariosa* is common here, as it was not in the other group.

D. JACK PINE TYPE. This is the most open of the series and occurs on the most sterile sands of the area. The only trees are *Pinus divaricata*, *Quercus coccinea*, *Prunus virginiana*, and seedlings of *Populus tremuloides* and *P. grandidentata*. All but the pine and oak are hardly more than shrubs. Besides the trees there occur on the jack pine areas the following low plants: *Pteris aquilina*, *Solidago nemoralis*, the three blueberries above mentioned (but rarely the huckleberry), *Arctostaphylos Uva-Ursi*, *Comptonia peregrina*, *Prunus*

[9] BEAL, W. J., Observations on the succession of forests in northern Michigan. 27th Ann. Rept., Bd. of Agric. Mich. 1888. pp. 74–78.

pennsylvanica, *P. pumila*, *Andropogon scoparius*, *A. furcatus*, *Danthonia spicata*, *Lacinaria cylindracea*, *Salix humilis*, *Cladonia rangiferina*, etc. This style comprises the worst part of what is called the "plains."

2. *Lowland types.*

For the most part the swamps which were originally wooded have not been denuded of forest. Where they contained white pine, that was taken out, leaving the other trees, which protected the undergrowth and soon produced a dense, almost jungle-like formation. Within the past few years the merchantable arbor vitae and tamarack have been removed from these swamps, but almost always enough small trees are left to produce shade. Also, the swamps have not been subjected to burning nearly so often as the uplands, and are generally in much more nearly their original condition than are the latter. The three types may be described as follows:

E. OPEN MEADOW TYPE. This is partly open hay meadow (largely of "blue-joint," *Calamagrostis canadensis*), partly of bulrush and cat-tail marsh, and partly of sphagnum bog. It grades into the other two types.

F. TAMARACK-ARBORVITAE SWAMP. This is the most typical swamp of the region. It contains *Larix laricina*, *Thuja occidentalis*, *Picea canadensis*, *P. mariana*, *Abies balsamea*, which form dense and often impassable thickets. In some localities Larix occupies almost all the ground to the exclusion of other trees, and in other places the same is true of Thuja. But there is not nearly so much tendency here for these two trees to form separate and distinct types as is found farther south.[10] There the tamarack seems to occupy the portions of the swamp lands which are most poorly drained, the arbor vitae growing in localities where drainage is more thorough, yet still not complete enough for the river swamp vegetation. Here the question of drainage does not appear to play so important a part.

G. MIXED SWAMP. This formation is found near swamp margins, especially where the underlying clay is near the surface. Thus it often occurs along lines where the hardwood forest reaches down

[10] For a description of the conditions farther south in the state, the reader is referred to the author's paper on Kent county, *loc. cit.*

toward a swamp. It may be looked upon as intermediate between the tamarack-arborvitae type and that of the hardwood. There is always a great mingling of species here. Among the trees are; *Larix laricina*, *Thuja occidentalis*, *Picea mariana*, *P. excelsa*, *Abies balsamea*, *Betula papyrifera*, *B. lutea*, *Fraxinus americana*, *Tsuga canadensis*, *Sorbus americana*, *Acer saccharum*, *Prunus serotina*, *Pinus strobus*, *Amelanchier canadensis*, etc., together with such low forms as *Rubus strigosus*, *R. villosus*, *Pteris aquilina*, *Lycopodium clavatum*, *Taxus minor*, *Alnus*, and *Ilex verticillatus*. The relative proportions of the different trees vary from one locality to another, so that nothing definite can be stated in this regard.

DISTRIBUTION OF FOREST TYPES.

The actual distribution of the types is shown by green lines on the accompanying map. The upland types are denoted by letters, each area bearing a letter to denote the type which it represents. Thus, *H* denotes hardwood; *W*, white pine; *N*, Norway pine; *J*, jack pine; and these letters stand for types *A*, *B*, *C*, and *D*, respectively. Of the lowland formations the open meadow is represented by the conventional sign for marsh where it exists over broad areas.

The main facts of distribution are presented in the following paragraphs. The upland and the lowland types will be considered separately.

Uplands.

The hardwood type occurs in this region always on soils which contain considerable amounts of clay. Such soils are always covered to a depth of several inches with leaf mold or humus, and in this layer the seedlings of hardwood and hemlock grow and thrive.

The white pine type occurs in the clayey Murray Hills, on the most clayey parts of Norway Hill, and on the great southeastern moraine, in T. 21 N., R. 2 W. These soils are often as clayey as those of many of the hardwood areas, but are higher and therefore better drained. It also occupies most of the gravelly ridge in T. 25 N., R. 2 W. Very often the swamp margins are occupied by this type also, especially where the slopes are not abrupt, a condition which gives humus a chance to collect in the sand.

The Norway pine type occupies gravelly ridges and loamy sand plains. The soil here is somewhat lighter than in the locations held by the last-named type, but it is generally too poor for profitable agriculture. As will be seen by a glance at the map, most of the uplands here studied were originally covered by this type.

The jack pine type occupies only the most thoroughly washed of the sand plains. The localities held by this open formation lie in the valley of the Au Sable. The parts lying about the headwaters of the Muskegon have abundant plains of loamy sand, but these support the type of Norway pine. This fact has no connection with the rivers themselves, however, for farther down the Muskegon are to be found typical jack pine barrens. The soil of the jack pine type is almost worthless for agriculture; it is light and dry, and where the surface is broken it is apt to be wind-blown, and often forms small traveling dunes.

Lowlands.

The distribution of the lowland type was not worked out with accuracy. Great difficulty was experienced in studying such areas, for the swamps are often almost utterly impassable. The greatest areas of open marsh encountered are marked on the map, as already described. There are doubtless many areas of like nature which were not seen at all, but these cannot be of very great extent. In all the swamps the ground is covered with a layer of humus, usually of the nature of peat, and there seems to be no difference in this substance between the sand and the clay areas. Neither is there any apparent difference in the swamp vegetation whether it is upon sand or clay.

RELATION BETWEEN DISTRIBUTION OF FOREST TYPES AND THAT OF SOIL TYPES.

The upland types seem to be very closely dependent upon the nearness of the underground water level to the surface and upon the nature of the soil. The former factor determines at once whether the vegetation shall be classified as upland or lowland. The distinction between these two classes is more evident on the surface than it is after closer study; it is difficult to state just how far the water level may recede from the surface and still support a lowland

type of the forest. Very few determinations have been made in this regard. MAYR[11] states for northern Wisconsin that where the water level is less than 2.5^{cm} below the soil surface, the vegetation is of the swamp form; while if it is lower than 2.5 to 5^{cm} the soil bears white pine or some other upland type. This was on sandy soil. WARMING[12] has determined the depth of water level in various soils in Denmark. He finds Juncus and Carex forms holding the ground until the water level is about 22.5^{cm} below the surface; with water at a depth of 30 to 37.5^{cm}, grasses grow well, forming what we should term a moist meadow. With the water from 45 to 60^{cm} below the surface, all grains grow well; this seems to represent our fertile uplands. With the water still lower the soils becomes poor for grains. Data from natural vegetation, so far as I know, have not been gathered.

The more water there is in a soil, the less is the access of air to the roots of plants growing therein. This is because air diffuses much more slowly when in aqueous solution than when in the form of a gas. Gas diffusion is checked by the filling of the interstices of the soil with water, and hence most of the oxygen which reaches roots in wet soil must do so by diffusing as a solute in the water. Some ordinary plants cannot grow without rather free access of oxygen to their roots, and so it follows that a soil saturated with water is very poorly adapted to their growth.[13] This is probably the main reason why saturated soils are usually occupied by a vegetation differing entirely in aspect from that found on soils which are drier; thus we have swamp or lowland types of vegetation contrasted with upland types. Swamp plants are able to live with a scanty supply of air to their roots; but since upland plants cannot, it is possible to have too much water in the soil for the well-being of the latter. Thus areas with much water are occupied by typical swamp plants, often perhaps because they alone are able to live in this situation.

[11] MAYR, H., Die Waldungen von Nordamerika. München. 1890.

[12] WARMING, E., Excursionen til Skagen i Juli 1896. Bot. Tid. **21**: 59–112. *figs. 4.* 1897. I am indebted to G. H. Jensen for an abstract of the article.

[13] WOLLNY, E., U. S. Dept. Agric. Exp. Sta. Record **4**:528–543, 627–641. 1893.

1. *Factors of distribution in the uplands.*

ORIGINAL DISTRIBUTION. Throughout the uplands, excepting in the narrow swamp borders and in the low clay plains about Houghton Lake, the underground water level is far from the surface, its depth varying from 3 to 25^m or even more.

Wherever the upland group occurs near the water level, it takes the form of one of two types, either the hardwood (on the low clay) or the white pine (on the low sand and loam). Farther above permanent water the former of these types occurs only in one locality, in the northwestern part of the area, and there upon loam. Where the water level is not near the surface, the white pine type occurs only on clay and loam. The Norway type is found throughout the area on loamy, or loamy and gravelly sand, and the jack pine type appears exclusively on sand which is hardly at all loamy and thoroughly washed. The distribution of the upland types just described may be tabulated as follows:

POSITION OF UNDERGROUND WATER LEVEL.

Soil	Near surface	Deep
Sand	B, C	D
Sandy loam	B, C	C
Clay loam	A, B	B (A)[14]
Clay	A, B	B

In the above table the different types are denoted by the letters already used in their description. It will be noticed that from clay to sand, with water level deeply seated, we have a series passing from the white pine type to that of the jack, through the Norway. A single exception to this is the hardwood area on clay loam in T. 25 N., R. 4. W, to be spoken of in a later paragraph. But with the water level near the surface, the series runs from the hardwood to the Norway type, the jack pine not occurring at all. This observation seems to agree with those made by MAYR[15] in northern Wisconsin. He states that sand ridges rising out of the swamps usually bear white pine on the slope, then Norway, and lastly the jack on the most elevated parts. The same author points out that white pine will grow on poor sand if the water is only near the surface. The same seems to be true here also.

[14] The hardwood in T. 25 N., R. 4 W.

[15] MAYR, H., *loc. cit.*, p. 207.

To explain the distribution of the different types, either of two hypotheses may be resorted to. As has already been mentioned, the finer the particles of the soil, the greater its power to lift and hold water above the underground level. It is well known, too, that some soils contain more of certain salts than do others. Thus, the reason for the observed distribution on the uplands may be sought for either in the water-retaining power of the soil or in its chemical constituents.[16] That the depth of the water table itself sometimes plays an important part in determining plant distribution is shown by the above table. Along a swamp margin the increased amount of water may influence the plant growth directly, but how much of the observed influence is to be considered as indirect is an open question. The presence of water alters a number of other soil factors.

First, it checks free access of air. Thus, if jack pine roots need more air than do those of Norway, this might explain why the former fails along the swamp borders and the latter takes its place.

Secondly, with increase in water content there follows a more equal distribution of the dissolved salts, for these can diffuse only through continuous water films, and the greater the cross-section of the latter, the more rapidly will diffusion take place. As a corollary to this statement, it follows that "leaching," the washing down of soluble salts out of the upper into the lower strata, cannot occur to any great extent in a soil which is constantly filled with water. Moreover the upward diffusion of salts during dry times would probably more than counteract the downward washing during heavy rains. The upper layers of a wet soil are apt to have more soluble salts after they have lain for a time than when first placed. This is of course on account of the evaporation at the surface, which increases the concentration of the soil solutions in the upper layers. Of course

[16] For early papers on this subject see:

THURMANN, J., Essai de phytostatique appliquée à la chaine du Jura. Berne. 1849.

NÄGELI, C., Sitzungsber. Akad. Wiss. München. 1865.

UNGER, Ueber den Einfluss des Bodens auf die Verteilung der Gewächse. Wien. 1836.

A more recent paper dealing with this question of soil physics and soil chemistry as influencing vegetation is COWLES, H. C., The influence of underlying rocks on the character of the vegetation. Bull. Amer. Bureau of Geog. **2**: 1–26. 1901.

this indirect effect cannot be exhibited unless there is a sufficient amount of salts in the deeper lying soil. But in a glaciated region such as this, there can be little doubt as to the presence of these relatively near the surface.

Thirdly, the checking of air access, coincident with the filling of the pores of the soil with water, must check the process of oxidation and thus accelerate the formation of humus. This seems to be a very important factor in determining vegetation.

Fourthly, the growth of micro-organisms in the soil, bacteria, etc., takes place much more rapidly in a moist than in a dry soil. However, excess of water is deleterious to the growth of many of these organisms, so that a soil may be too wet for them; but flooding is not so fatal in sand as in finer soils.[17] It is well known that soil bacteria and mycorhizal forms are very important in increasing the amount of nitrates in the soil, and thus it appears that a moist soil, even a wet soil, if it be sandy, will gain nitrates much more rapidly than a dry one.

The comparative rapidity of temperature changes in moist and dry soils may have considerable importance in regard to plant growth. A dry soil is subject to much more sudden and rapid changes of temperature than is a moist one when the soils are exactly alike, as I have shown by actual tests.

The points of difference between a moist and a wet soil may be tabulated as follows:

Condition of soil	Dry	Moist	Wet
Water for roots	Too little	Enough for most plants	More than needed for most plants
Soluble salts originally near surface	Sometimes leached farther down	Still near surface	Still near surface
Soluble salts originally in lower layers	Sometimes leached farther down	Partly in upper layers	Partly in upper layers
Humus content	None	Some	Plentiful
Oxygen content	Plentiful	Some	Little
Micro-organisms	None	Optimum	Few
Nitrates	Little	Much	Some
Temperature changes	Rapid	Less rapid	Slow

Whether these points are determined by nearness of the underground water level or by the capillary power of the soil, there appears to be no doubt that the amount of water in the layers near the surface practically determines the nature of the vegetation in this region. Besides the general discussion of this matter to be found in

[17] GAIN, E. Action de l'eau du sol sur la végétation. Rev. Gén. Bot. 7:16–26, 71–84, 123–137. 1895.

WARMING and SCHIMPER (*loc. cit.*), the reader may refer to GAIN[18] and HEDGCOCK.[19]

Of the upland series, the hardwood type of vegetation seems to need the most water, the most soluble content, and the most humus. Probably this is the reason why this type occupies the moister soils of the upland, no matter whether these are moist through nearness to the underground water table or through the lifting power of the soil itself. The types of white, Norway, and jack pines seem to require less water in the order of their arrangement. Probably the Norway and jack pines require more air in the soil than either the hardwood or the white pine. The typical tree forms of both these last-named types occur in the mixed swamp quite commonly, but I have yet to see either Norway or jack pine in soil which is wet the greater part of the year. Throughout the region it seems that each type occupies soils which correspond in water content to its needs. It must be remembered here that a sandy soil near the water level may contain much more water than a loamy one where the water is farther from the surface. This idea offers a possible explanation for the occurrence of hardwood on low loam in T. 25 N., R. 4 W. Addition of surface humus has also, perhaps, raised the water holding power of the soil to the neighborhood of that manifested by clay itself. The subsoil is such here that the white or Norway type might be expected.

PRESENT DISTRIBUTION. The statement so frequently met with that white pine will not come up after it has once been cut off and the ground burned over seems to strike wide of the truth in this region. I have visited almost every square mile of the uplands and am thoroughly convinced that scattering seedlings of white pine are now evident on practically all areas originally covered by that species, which have not been recently subjected to the action of fires. Seedlings of the Norway, however, are now more numerous on these areas than are those of the white pine itself. They are plentiful throughout the region on light soils excepting the very lightest.

[18] GAIN, E., Recherches sur le rôle physiologique de l'eau dans la végétation. Ann. Sci. Nat. Bot. VII. **20**:65–215. 1894.

[19] HEDGCOCK, C. G., Botanical Survey of Nebraska: Studies in the vegetation of the State, II. Lincoln. 1902.

Fires prevent the young growth of the white pine and also prevent humus formation. Thus, as long as the latter are allowed to continue, the water capacity is not apt to rise and the growth of nitrifying bacteria is not apt to increase; but the presence of a few white pine seedlings is evidence that the species can grow if protected. Indeed the best young stands of any kind that I have seen are of this tree, and they promise exceedingly well for reforestation.

As has been said, the Norway pine is coming in quite freely in the areas originally covered by this species and the white pine. The degeneration goes no further, however; I have almost never seen even individual jack pines appearing in any of these areas. Indeed, there is some evidence that the Norway pine is gradually advancing its seedlings into the areas held by the jack pine.

The hardwood forest reappears quite rapidly when cut. This is doubtless in part due to the fact that this material does not burn so readily nor so violently as do the pines. The scattered white pines which formerly characterized some of these forests in the eyes of the lumberman are not returning. They are perhaps only a relic of a past generation of forest.[20] Hemlock is reproducing well and will return with the beech and maple if through lack of humus the soil does not become too dry for the seedlings. The sugar maple is the best for reclaiming cut-over lands. Its seedlings stand close together and do not seem to suffer from one another's shade.

The work of SHERRARD[21] in this region resulted in a map and statistical study of the tree growth of township 25 N., R. 4 W, as well as a general discussion of the forestry conditions of the reserve. The township thoroughly studied by this author originally contained practically no white pine, but the other types are well represented. SHERRARD'S "oak flat" and "oak ridge" are all original Norway pine land. For statistics of growth, etc., the reader is referred to his paper.

[20] See the author's Kent county paper, *loc. cit.;* also WHITFORD, H. N., The genetic development of the forests of southern Michigan. BOT. GAZ. **31**:289–325. 1901.

[21] SHERRARD, T. H., The Michigan forestry reserve. Report Mich. Forestry Commission **1902**: 28–54. 1903.

2. *Factors of distribution in the lowlands.*

The three types of lowland vegetation seem also to follow in some degree the conditions of soil moisture. In this case it seems better, however, to arrange the types in the reverse order and to present them as following conditions of drainage. As has been stated, all three types are composed of forms which can withstand a great deal of moisture. No positive evidence can be given as to whether or not there is any difference in water content between the soils of the open meadow and those of the tamarack-arborvitae forest. Nothing has been made out regarding the conditions which decide in favor of one or the other of these; but the mixed type is always found on the better drained portions, where there are hummocks raised out of the saturated soil, and where the general level is a few inches higher. Often this better drainage seems to come about merely by accumulation of vegetable débris, a fact which suggests that perhaps in time the conifer swamp might give way to the mixed, and at last possibly to the hardwood upland type.

Attention has already been called to the fact that this series of types have not been seriously altered by the hand of man. The large white pines have been taken from the mixed swamps, as have also many of the most valuable tamaracks and arbor vitae, but the forest conditions have not generally been destroyed.

RELATION OF THE VEGETATION TO THAT OF KENT COUNTY.

The predominance of the pines in the region under discussion is an expression of the fact that the flora here is a typical northern one. Only one pine (the white) is found in Kent county, and there it grows in poorer soil than it holds here. The presence of hickory and the better growth of the black, red, and white oaks in the more southern area is an indication of a more southern flora. The factor which keeps the jack pines out of the more southern county may be a climatic one; this species occurs with the white pine on the dunes at the extreme southern end of Lake Michigan.

The hardwood forests of the two regions are very nearly the same in character. In the northern part of Kent county the hemlock begins to be an important tree in this group, as it is farther north.

A study of the transition zone between these two areas will be necessary before the working out of the exact relation of the various societies can be attempted.

RELATION OF THE VEGETATION TO THAT FARTHER NORTH.

The student of plant distribution who has formed any definite theories as to the relation of plant societies to topography and soils from the southern part of the state and from Indiana and Illinois will be much surprised if not actually shocked by a visit to the region of the straits of Mackinaw. On the island of Mackinac, for example, occur most of the tree forms found in Kent county, but growing apparently without relation to the soil condition. Norway and white pines, beech, sugar maple, red maple, tamarack, arbor vitae, balsam fir, basswood, etc., will be found growing side by side on the well-drained uplands in clay or sand or loam, or even partially bare rock. As to the reasons for this nothing can be said before more of the area has been studied in detail.

CONCLUSION.

It appears from these investigations that the main factor in determining the distribution of the forests on the uplands of this region is that of the size of soil particles, the sorting of which dates back almost entirely to the close of the last glacial epoch. The size of particles determines the amount of air and moisture in the soil, and these in turn determine the amount of humus formation and the growth of nitrifying organisms, and perhaps also to a certain extent the amount of soluble salts in the surface layers.

A factor of less importance, because applicable only over small areas, is the nearness of the underground water level to the surface. This affects the uplands only along swamp borders.

In a broad way, physiography may be said to determine the vegetational distribution here.[22] The physiographic features are largely ones of glacial topography or are traceable directly to these. Geological factors, in one way or another, have of course determined

[22] For an excellent elaboration of this idea see COWLES, H. C., The physiographic ecology of Chicago and vicinity. BOT. GAZ. **31**:73–182. 1901. Also, The plant societies of Chicago and vicinity, Bull. Geog. Soc. of Chicago **2**:1–76. 1901. Also, The physiographic ecology of northern Michigan, Science N. S. **12**:708, 709. 1900.

the distribution of surface soils and the distance below the surface of the ground water level.

It is probable that many dry soils may at length become moist enough to support one of the more moisture loving types of vegetation, simply by increase of humus content, which must go on slowly at first but more rapidly as the amount increases. This is merely an application of one of the general principles of forest succession pointed out by WHITFORD (*loc. cit.*).

The lowlands are covered with a vegetation complex of species such that they can bear excess of water and paucity of oxygen in the soil. From the open meadow and coniferous swamp we pass, with better and better drainage, through the mixed swamp to the hardwood or the white pine of the uplands.

It appears that the natural reforestation of the pine areas, with Norway pine, and to some extent at least with white pine, will take place if the fires can be suppressed.

THE UNIVERSITY OF CHICAGO.

NOTE.— Since the preparation of this paper, a similar conclusion has been reached in regard to sterility in agricultural soils by WHITNEY and CAMERON, Bull. 22, Bureau of Soils, U. S. Dept. Agric. 1903. Also, it has been shown by actual field test that coarseness of soil particles alone can produce sterility in spite of a plentiful supply of water. See LIVINGSTON and JENSEN, An experiment on the relation of soil physics to plant growth. BOT. GAZ. 38: 67–71. 1904.